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Are teeth useful in estimating stature?

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ABSTRACT

Estimating stature is an important step in reconstructive identification of skeletonized and dismembered human remains. While numerous body parts such as the skull and long bones have been used for the purpose, the dentition has seldom been applied. The present study has ventured to ascertain the usefulness of tooth crown measurements in stature prediction. Buccolingual and mesiodistal dimensions of all teeth (except third molars) and stature measurements were obtained from 95 living adults (47 females, 48 males). Correlation analysis revealed that 21 of the 56 tooth crown variables had a low albeit statistically significant correlation to stature ($p < 0.05$); correlation matrix computed for the crown variables showed significant inter-correlations between most teeth (problem of multi-collinearity). Therefore, instead of regular least square regression analysis, ridge regression was performed for the dentition, which revealed a moderate but statistically significant correlation to stature ($R = 0.68$; $p < 0.0001$). The ridge regression equation derived had a standard error of estimate (SEE) of 8.09 cm. The multiple correlation for tooth dimensions is lower to, and the SEE larger than, most other body parts. The moderate correlation is probably due to early completion of growth of tooth crowns vis-à-vis other parameters such as long bones that mature later and have a higher stature-correlation. This indicates that the dentition may be used only as a supplement to more robust indicators of stature.

1. Introduction

Estimating stature, along with age, sex and race, is one of the four pillars of the anthropological protocol[1] and may be essential in preliminary screening and reconstructive identification of skeletal remains. Stature is shown to have a definite and proportional relationship with many parts of the human body such as the cranial and facial bones,[2–4] long bones,[5–7] trunk[8] and foot bones.[9,10] Stature estimation from the dentition, however, has seldom been explored. Björk[11] found a low correlation between tooth widths of maxilla and tibia length. Considering high correlation between tibia and stature[7] it may be inferred that tooth dimensions are not well correlated to stature. Indeed, Filipsson and Goldson[12] found a very weak correlation for the sum of maxillary central incisor and canine dimensions to stature. These authors, however, attributed the near-absence of relationship to their sample size and believed that it would be surprising if no correlation were to exist between teeth and stature. Although, dentin — which forms the bulk of the tooth and determines the dimension of the tooth — originates from the ectomesenchyme (neural crest cells) and long bones from the mesoderm, both are basically mesenchymal tissue (connective tissue) that have similar structural components (with collagen forming the organic matrix and hydroxyapatite crystals being the inorganic component).[13,14] Hence, it is reasonable to presume a correlation between tooth dimensions and stature in an individual. Recently, Kalia et al.[15] examined mesiodistal dimensions of maxillary anterior teeth and found a low but statistically significant correlation to stature, while Lima et al.[16] observed relatively high accuracy in stature prediction for the same teeth. However, studies that correlated tooth dimensions to stature and/or determined its effectiveness in stature prediction have restricted to using maxillary anterior teeth[12,15,16] and the correlation of the dentition, as a whole, is still unknown. A 'good' correlation between dental measurements, in general, and stature can be useful in anthropological and forensic identification since teeth are the strongest structures in the body and survive a variety of peri- and postmortem alterations. The

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dentition's resistance has enabled its routine application in confirmative identification as well as in anthropological and forensic reconstructive endeavors such as assessment of sex, age and population affinity.[17–19] The objectives of this study are, therefore, to determine the degree of relationship between tooth measurements as-a-whole and stature, and the dentition's expected usefulness in stature prediction.

2. Materials and methods

2.1. Sample and tooth measurements

The sample comprised of dentitions from 95 individuals (47 females and 48 males), all young adults between 20 and 32 years of age who originated from this country. Following informed verbal consent, impressions of the teeth were made using irreversible hydrocolloid (alginate) material and casts poured in dental stone. Irreversible hydrocolloid impression does not provide the best possible dimensional stability for accurate reproduction of dental casts, especially when compared to elastomeric impression material. However, its use in previous forensic tooth measurement-based studies,[20,21] relative ease in impression-making and its inexpensive nature influenced its usage here. Buccolingual (BL) and mesiodistal (MD) dimensions of all teeth, except third molars, were measured on the casts using a digital caliper calibrated to 0.01 mm (Altraco Inc., Sausalito, USA). The MD dimension was defined as the greatest distance between contact points on the approximate surfaces of the tooth crown and was measured with the caliper beaks placed occlusally and aligned with the long axis of the tooth (Fig. 1).[22] If teeth were rotated or misaligned, measurements were taken between points on the approximate surfaces of the crown where it was considered that contact with adjacent teeth would normally occur.[22] The BL measurement was defined as the greatest distance between the labial/buccal surface and the lingual/palatal surface of the tooth crown, measured with the caliper held at right angles to the MD dimension.[23] Overall, 56 tooth variables (28 teeth $\times$ 2 variables, i.e., MD and BL dimensions) were obtained for each study subject. Measurements were repeated on 20 randomly selected casts to test for potential intra-observer variation.

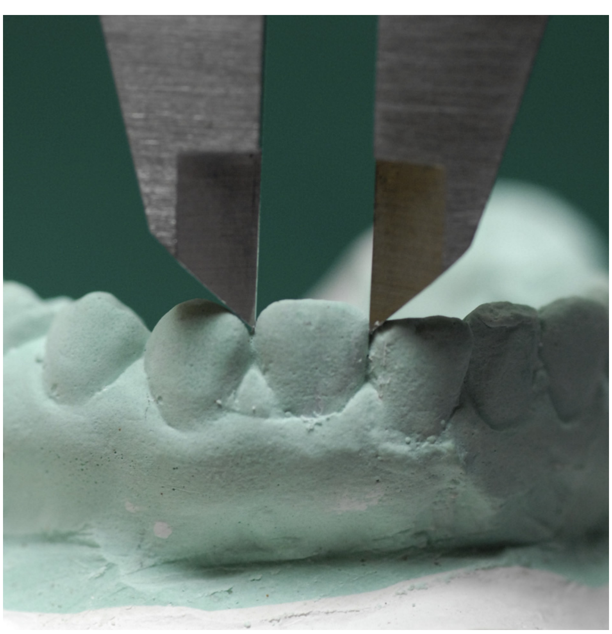

Fig. 1. Mesiodistal measurement being taken between the contact areas for a lower right lateral incisor.

2.2. Stature measurement

Stature was measured as the vertical distance from the vertex to the floor. The measurement was obtained by making the subject stand erect and barefooted — with the heels in close contact with each other — on a firm horizontal resting plane,[4,7] in front of a scale calibrated to 0.1 cm on a rigid vertical plane. The subject's back was positioned as straight as was possible, and achieved by rounding or relaxing the shoulders,[4] with the shoulder blocks and buttocks touching the vertical plane. The head was oriented in the Frankfurt Horizontal plane, which was achieved by adjusting the face such that the lateral palpebral commissure and the tip of the pinna were in a horizontal plane parallel to that of the feet.[7] An L-shaped board — with one arm sliding against the vertical plane — was brought down on to the subject's head[4] and the stature read off the scaled vertical plane. Stature was re-measured on 20 randomly selected subjects, also to assess possible intra-observer differences.

2.3. Statistical analyses

Potential intra-observer variation was assessed using the paired samples *t*-test. Correlation of each of the 56 tooth variables to stature was then ascertained. Individual tooth correlation to stature was computed using ordinary least square regression analysis. For the combined teeth, however, a different approach was taken: considering that tooth dimensions may be inter-correlated, a correlation matrix of the tooth variables was computed. A high correlation was observed between most tooth variables and, therefore, ridge regression — a method that is less sensitive to multicollinearity than least squares regression — was applied. While other methods, such as principal component regression, exists for combating multicollinearity, ridge regression was applied since a test revealed stronger correlation between the tooth variables and stature for this type of statistical analysis.

In ridge regression, the parameter estimates are obtained from

$$\beta(\theta) = (X'X + \theta l)^{1}\, X \neq y \tag{1}$$

where $\theta \geq 0$ is a constant, y is the dependent variable (or vector), X is the matrix of independent variables, l is the identity matrix, and X' is the transpose of the matrix X. Generally, values of θ in the interval $0 \leq \theta \leq 1$ are appropriate. The ridge estimator $\beta(\theta)$ is not an unbiased estimator of β, as is the ordinary least squares estimator $\beta_{\sim}$. Thus, ridge regression seeks to find a set of regression coefficients that are more 'stable' in the sense that they have a small mean square error.

Since multicollinearity usually results in ordinary least squares estimators that may have extremely large variances, ridge regression is suitable for situations where the multicollinearity problem exists. To obtain the ridge regression estimator from Equation (1), we must specify a value for the constant θ. Generally, there is an 'optimum θ' for any problem, but the simplest approach is to solve Equation (1) for several values of θ in the interval $0 \leq \theta \leq 1$, following which a plot of the value of $\beta(\theta)$ is constructed. This display is called a *ridge trace*. The approximate value for θ is chosen subjectively by inspection of the ridge trace. Typically, its value is chosen to obtain stable parameter estimates. Generally, the variance of $\beta(\theta)$ is a decreasing function of θ, while the squared bias $[\beta - \mathrm{E}(\beta(\theta))]2$ is an increasing function of θ. Choosing the value of θ involves trading off these two properties of $\beta(\theta)$.

The statistical analyses were undertaken in SPSS 10.0 statistical program (SPSS Inc., Chicago, USA; now IBM Corp., Armonk, USA) and STATISTICA for Windows (StatSoft, Inc., Tulsa, USA).

3. Results

The paired *t*-test to evaluate potential intra-observer variation in stature measurements revealed relatively strong agreement, with statistically insignificant differences ($p > 0.05$). The tooth measurements also showed insignificant statistical differences ($p > 0.05$) for all but two variables. The average difference between the base and repeat measurements for the two variables, namely BL dimension of the maxillary right first molar and MD dimension of the maxillary left lateral incisor, was 0.08 mm and 0.12 mm, respectively, which may be considered as practically insignificant.

Correlation of the individual tooth variables to stature revealed *r* values ranging from −0.10 to 0.33. Seven variables had a negative, albeit statistically insignificant, correlation. Of the 56 tooth variables, 21 had statistically significant correlation ($p < 0.05$) to stature (Table 1).

With regards to the ridge regression analysis, the ridge trace suggests $\theta = 0.04$, and the ridge regression obtained using a forward selection procedure selected 18 of the 56 variables. The coefficients and constant of the ridge regression equation are depicted in Table 2. The multiple correlation coefficient (R) between stature and tooth measurements for these 18 variables was 0.68 ($R^2 = 0.46$; Adjusted $R^2 = 0.33$; $l = 0.04$; $F(18,76) = 3.5587$) and analysis of variance for the ridge regression showed that it was significant ($p < 0.0001$). The standard error of estimate (SEE) for the ridge regression was 8.09 cm. The coefficients and constant of this ridge regression equation are depicted in Table 2.

When all 56 variables were entered in to the regression analysis, a higher multiple correlation coefficient (R) of 0.83 ($R^2 = 0.70$; Adjusted $R^2 = 0.25$; $l = 0.0.04$; $F(56,38) = 1.5525$) and SEE (8.56 cm) were obtained. The coefficients and constant of this ridge regression equation are depicted in Table 3. However, the analysis of variance for this ridge regression was statistically insignificant ($p > 0.05$) — the R^2 is larger than in the forward selection procedure, but the model does not fit well owing to multicollinearity. Hence, this result will not be commented on further.

The R value reflects the strength of correlation of ridge regression of the teeth to stature (closer the value is to 1, stronger the correlation); SEE, on the other hand, tends to predict the deviation of estimated stature from actual stature — a low SEE indicates greater reliability of a variable in stature prediction. Although use of the SEE has been criticized,[24,25] it has frequently been used as a measure of accuracy of stature estimation equations.[2–4,6,9,15,26–31] Hence, in the present study, SEE is reported for the purpose of comparison with those derived previously for other body parts, analogous to the comparison undertaken in a few recent papers.[8,28,29]

Table 1
Correlation of tooth variables to stature.

Dimension	Tooth	Upper jaw		Lower jaw	
		Right	Left	Right	Left
Buccolingual	Central incisor	0.17	0.15	0.05	0.07
	Lateral incisor	0.08	0.18	−0.05	0.01
	Canine	0.26*	0.29*	0.27*	0.23*
	First premolar	0.08	0.14	0.12	0.15
	Second premolar	0.11	0.14	0.32*	0.25*
	First molar	0.18	0.20	0.30*	0.33*
	Second molar	0.19	0.29*	0.16	0.30*
Mesiodistal	Central incisor	0.08	0.14	0.25*	0.20
	Lateral incisor	0.21*	0.17	0.18	0.17
	Canine	0.24*	0.21*	0.18	0.28*
	First premolar	−0.02	−0.05	−0.03	0.01
	Second premolar	−0.04	−0.10	0.14	−0.06
	First molar	0.21*	0.16	0.21*	0.31*
	Second molar	0.21*	0.29*	0.11	0.23*

* Statistically significant ($p < 0.05$).

Table 2
Coefficients, constant and the level of significance of the contributing tooth variables in the ridge regression when a forward selection procedure was applied.

Tooth variable	BETA	S.E. of BETA	B	S.E. of B	$t(76)$	p
BL LLM1	0.22	0.14	4.2682	2.74	1.55951	0.123
BL ULC	0.14	0.11	2.6486	2.05	1.29244	0.200
MD ULP2	−0.50	0.12	−8.7515	2.15	−4.0642	0.000
MD URC	0.23	0.12	5.1168	2.57	1.98746	0.050
BLURP1	−0.36	0.12	−6.39	2.09	−3.0509	0.003
BL LRP2	0.19	0.12	3.4356	2.08	1.65412	0.102
BL ULM2	0.28	0.15	3.0493	1.59	1.91784	0.059
MD LLCI	0.24	0.10	5.6073	2.35	2.38589	0.020
BL LLP2	0.25	0.11	4.4697	2.06	2.17303	0.033
BL LLM2	−0.31	0.15	−6.2401	2.94	−2.1193	0.037
BL LRLI	−0.12	0.09	−2.3144	1.81	−1.2802	0.204
MD URLI	0.16	0.10	2.3976	1.48	1.61507	0.110
BL URLI	−0.18	0.11	−3.5602	2.23	−1.5983	0.114
MD ULCI	−0.15	0.11	−2.5696	1.89	−1.3562	0.179
BL URCI	0.13	0.11	2.2081	1.86	1.18605	0.239
MD LLM2	−0.25	0.15	−2.8747	1.69	−1.7001	0.093
BL LLM2	0.24	0.17	3.3579	2.38	1.40925	0.163
MD URM2	0.13	0.10	1.7474	1.38	1.2619	0.211
Intercept			116.12	24.2693	4.78	0.000

MD = mesiodistal; BL = buccolingual; UR = upper right; UL = upper left; LR = lower right; LL = lower left; CI = central incisor; LI = lateral incisor; C = canine; P1 = first premolar; P2 = second premolar; M1 = first molar; M2 = second molar.

4. Discussion

4.1. Correlation of tooth dimensions to stature

Evaluation of individual tooth variables showed a low correlation to stature (r, −0.10 to 0.33). A rather strange finding was the negative but statistically insignificant correlation ($p > 0.05$) to stature of seven tooth variables. Six of these were mesiodistal dimensions of premolars, suggesting some form of proximal wear for these teeth at an early age in taller subjects, contributing to a decrease in the tooth dimension; another possible reason may be plasticity, which is the ability of the dentition to physically adjust to changing environmental conditions. Such plasticity may have been expressed on certain dimensions of later erupting teeth, such as the MD measurements of premolars, due to a lack of space in the dental arches. Again, this may have been pronounced in taller subjects.

Overall, of the 56 variables measured, 21 were statistically significant (Table 1) and only 10 of these contributed to the ridge regression that used a forward selection procedure (Table 2), suggesting that statistically significant individual tooth correlation has little bearing on the dentition's correlation to stature as a whole. Overall, the results reveal a moderate but statistically significant correlation of the dentition to stature ($R = 0.68$; $p < 0.0001$). Therefore, attempts at using the dentition in stature prediction should apply a stepwise process so that the best possible tooth variables are selected from the entire dentition, rather than examining a select group of tooth variables — which was the approach followed previously[12,15]; also, instead of applying conventional least squares regression analysis,[15] or principal component regression (our unpublished results yielded $R = 0.54$ for the entire dentition), it is prudent to use ridge regression. Some authors[15] regressed the sum of anterior tooth dimensions to stature and did not consider the possibility of individual tooth variables having varying correlation to stature. When multiple independent variables (e.g., tooth crown dimensions) are added, it is assumed that they are contributing the same amount of information to the dependent variable (e.g., stature).[32] As demonstrated in the present study this is not the case and, hence, ridge regression is recommended.

Table 3
Coefficients, constant and the level of significance of all 56 tooth variables when entered together in to the ridge regression analysis.

Tooth variable	BETA	S.E. of to BETA	B	S.E. of B	t(76)	p
BL URCI	0.08	0.22	1.4183	3.91	0.3625	0.719
MD URCI	−0.06	0.24	−0.9154	3.90	−0.23478	0.816
BL URLI	−0.29	0.22	−5.7703	4.37	−1.31943	0.195
MD URLI	0.10	0.23	1.5215	3.41	0.44573	0.658
BL URC	−0.71	0.33	−13.0605	6.09	−2.14457	0.038
MD URC	0.50	0.29	11.2366	6.46	1.73886	0.090
BL URP1	−0.55	0.33	−9.9641	5.86	−1.70125	0.097
MD URP1	0.34	0.26	7.3263	5.55	1.32079	0.194
BL URP2	0.10	0.26	1.3747	3.61	0.38074	0.706
MD URP2	−0.04	0.20	−0.5503	2.70	−0.20368	0.840
BL URM1	−0.33	0.23	−4.9625	3.48	−1.42745	0.162
MD URM1	0.40	0.24	7.4015	4.52	1.63742	0.110
BL URM2	0.12	0.27	1.6023	3.47	0.4612	0.647
MD URM2	0.23	0.19	3.0937	2.53	1.22346	0.229
BL LRCI	0.17	0.20	3.0204	3.57	0.84509	0.403
MD LRCI	−0.24	0.22	−4.0034	3.62	−1.10737	0.275
BL LRLI	0.13	0.26	2.3147	4.80	0.48184	0.633
MD LRLI	−0.04	0.23	−0.7171	4.01	−0.17894	0.859
BL LRC	0.55	0.24	10.5964	4.52	2.34663	0.024
MD LRC	0.12	0.29	2.3782	6.08	0.39106	0.698
BL LRP1	0.07	0.28	1.1321	4.66	0.24295	0.809
MD LRP1	−0.34	0.28	−7.4195	6.13	−1.21037	0.234
BL LRP2	−0.13	0.30	−1.9423	4.69	−0.41423	0.681
MD LRP2	−0.85	0.27	−14.8670	4.67	−3.18353	0.003
BL LRM1	0.50	0.21	6.7229	2.87	2.34536	0.024
MD LRM1	−0.50	0.25	−8.3900	4.19	−2.00113	0.053
BL LRM2	0.63	0.28	6.8344	3.06	2.23335	0.031
MD LRM2	−0.10	0.23	−1.2457	2.79	−0.44612	0.658
BL LLCI	−0.20	0.23	−4.1580	4.86	−0.85486	0.398
MD LLCI	0.46	0.21	10.5845	4.77	2.22063	0.032
BL LLLI	0.18	0.21	3.7071	4.26	0.87038	0.390
MD LLLI	−0.14	0.22	−3.6235	5.65	−0.64157	0.525
BL LLC	0.09	0.23	1.6810	4.01	0.41869	0.678
MD LLC	−0.13	0.24	−3.1871	5.69	−0.56014	0.579
BL LLP1	−0.39	0.25	−7.3842	4.85	−1.5227	0.136
MD LLP1	0.17	0.20	3.8481	4.52	0.85191	0.400
BL LLP2	0.41	0.20	7.4626	3.65	2.04422	0.048
MD LLP2	−0.12	0.19	−1.6964	2.68	−0.63267	0.531
BL LLM1	−0.11	0.27	−2.0452	5.23	−0.39097	0.698
MD LLM1	0.10	0.27	1.6146	4.47	0.36153	0.720
BL LLM2	0.46	0.36	6.4447	4.95	1.30315	0.200
MD LLM2	−0.84	0.32	−9.5779	3.62	−2.64779	0.012
BL LRCI	0.56	0.28	10.2601	5.06	2.02841	0.050
MD LRCI	0.06	0.21	1.5071	5.28	0.28565	0.777
BL LRLI	−0.48	0.22	−9.4700	4.27	−2.21952	0.032
MD LRLI	0.08	0.18	2.3293	5.26	0.44305	0.660
BL LRC	−0.03	0.20	−0.4947	3.72	−0.1329	0.895
MD LRC	0.23	0.21	5.6046	5.00	1.12049	0.270
BL LRP1	0.16	0.23	3.2527	4.63	0.70268	0.487
MD LRP1	−0.06	0.23	−1.5107	5.59	−0.27031	0.788
BL LRP2	0.34	0.21	5.9636	3.68	1.61918	0.114
MD LRP2	−0.13	0.18	−2.3271	3.12	−0.74504	0.461
BL LRM1	0.17	0.20	3.4681	4.16	0.8338	0.410
MD LRM1	−0.03	0.23	−0.5409	3.66	−0.14784	0.883
BL LRM2	−0.32	0.27	−6.4136	5.55	−1.15545	0.255
MD LRM2	−0.08	0.19	−1.1171	2.82	−0.39674	0.694
Intercept			106.2413	36.9239	2.87731	0.007

MD = mesiodistal; BL = buccolingual; UR = upper right; UL = upper left; LR = lower right; LL = lower left; CI = central incisor; LI = lateral incisor; C = canine; P1 = first premolar; P2 = second premolar; M1 = first molar; M2 = second molar.

4.2. Comparison of reliability of stature estimation from teeth with other body parts

A comparison of the correlation of tooth crowns to stature in previous studies[12,15] with correlation to stature of cranial and other parameters of the body[2–5,7–10] shows that tooth variables have some of the lowest correlation. (Note that the use of a different statistical approach in Lima et al.[16] precludes comparison to the results published in that study.) The use of the dentition as a unit herein, and through the application of ridge regression, improved the correlation to moderate levels ($R = 0.68$), rendering it comparable to that of various parameters of the cephalo-facial complex,[3,4] in between the extremes of the correlation of variables of the hand and foot bones,[5,9] but lower than that of the long bones.[7,27,30,31,33] The SEE from the ridge regression analysis was 8.09 cm, which is more than the SEEs obtained in most previous studies, including cranial and cephalo-facial dimensions[3,4,27,28] and other parameters from the extremities of the body.[6,7,9,26,30,31,33] While the correlation reported here for the dentition vis-à-vis stature is an improvement over previous studies,[12,15] teeth as a *unit* have a moderate correlation, which is in contrast to the moderate-to-high correlation for *individual* parameters of the cephalo-facial complex,[3,4] the hand and foot,[5,9] long bones[30,33–35] and extremities.[36]

The tendency of tooth crown dimensions to have a moderate correlation to stature — particularly when compared to long bones — may be attributed to their differences in the time of growth completion. While tooth crown completion of all permanent teeth (except third molars, which have been excluded in this study) occurs by the age of ten years (range, 8–12 years),[37] the closure of the epiphyseal lines of long bones (which ultimately affects stature) may take place from 17 to 19 years.[38,39] Hence, unlike teeth, long bone length may be influenced by several environmental factors such as diet and exercise until much later ages and for an extended period. During the same period (approx. 12–19 years of age), however, tooth crown dimensions are not affected — since no regeneration of enamel occurs upon crown completion, there is no possibility of addition to the tooth crown. Even if teeth did react to environmental stimuli, it would be in the form of excessive dentin formation *within* the tooth and toward the pulp.[14] Therefore, although teeth and the long bones are mesenchymal in origin (dentin from ectomesenchyme and long bones from mesoderm), the differences in their timing of growth completion probably renders tooth crown dimensions with only moderate correlation to stature. Overall, the moderate tooth–stature correlation and relatively high SEE in the present study suggest that the dentition may only be used as a supplementary method to other more accurate variables of the skeletal system.

Ethical approval

Ethical approval was obtained from the Institutional Ethical Committee (Ethical Clearance dated 16th July 2007 and 7th October 2009).

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Conflict of interest

None declared.

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